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ORIGINAL PAPER

One and two-year clinical outcomes for a polyethylene glenoid with a fluted peg: one thousand two hundred seventy individual patients from eleven centers

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Abstract

Purpose Clinical shoulder science lacks a benchmark against which the early clinical value of new glenoid components can be compared; such a benchmark may be derived from a multicenter study of patients receiving an established, internationally used design of glenoid component.

Methods We obtained data from 11 centers on 1270 patients having total shoulder arthroplasty using an all-polyethylene component with a fluted central peg. We analyzed *individual* patient outcomes at 1 and 2 years after surgery. We compared the improvement for each patient to the minimal clinically important difference (MCID) and calculated each patient's improvement as a percent of maximal possible improvement (MPI).

Level of Evidence: Level IV Therapeutic

Investigation performed at University of Washington Department of Orthopedics and Sports Medicine, Seattle WA

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Results The preoperative scores improved from SST 3 ± 2, ASES 37 ± 15, Constant score 36 ± 16, and Penn score 30 ± 19 to SST 10 ± 2, ASES 90 ± 12, Constant 76 ± 13, and Penn 80 ± 24 ($p < 0.001$ for each). A high percentage of patients improved by more than the MCID (SST 96%, ASES 98%, Constant 94%, Penn 93%) and obtained improvement of at least 30% of the MPI (SST 95%, ASES 98%, Constant 91%, Penn 87%). The clinical outcomes realized with this glenoid design were not worse for the 41% of shoulders with preoperative type B glenoids or for the 30% of shoulders with more than 15 degrees of glenoid retroversion.

Conclusions Individual patients from 11 international practices having total shoulder arthroplasty using a basic glenoid component design obtained highly significant clinical outcomes, providing a benchmark against which the early outcomes of new designs can be compared to determine whether they provide increased clinical value.

Keywords Glenoid · Ingrowth · All-polyethylene · Peg · Clinical outcomes · Minimal clinically important difference · Percentage of maximal possible improvement

Introduction

Background and rationale

Total shoulder arthroplasty is a widely used surgical treatment for glenohumeral arthritis. Glenoid component failure has been identified as the major mechanical cause of failure of total shoulder arthroplasty [1–10]. A recent review indicates that this is still the case: glenoid loosening accounted for 38% of all total shoulder complications [11]. In an attempt to address the high rate of glenoid failure, new glenoid components are being submitted and cleared by the U.S. Food and Drug Administration's 510 (k) process each year (Fig. 1). However, in spite of the introduction of these new designs, a recent analysis failed to show evidence of substantially improving outcomes for total shoulders over the last two decades [12]. It is difficult to know whether the new designs of glenoid components are yielding results that exceed the results of components that have been in widespread international usage for many years.

One of the commonly used glenoid designs is an all-polyethylene component that is fixed to bone with cemented peripheral pegs and an uncemented fluted central peg. The outcomes for patients receiving this glenoid component have been the subject of recent reports by surgeons from different countries [13–31]; however, the patients in these articles have not been analyzed together as a cohort of individuals. We contacted the authors of these publications requesting their most recent data on each patient having a total shoulder using this glenoid design so that we could perform a "by patient" analysis in which the clinical outcome for each patient was weighted individually.

We hypothesized that a great majority of patients with glenohumeral arthritis from 11 independent centers using this design of glenoid component would achieve clinically significant improvement following total shoulder arthroplasty assessed by generally accepted outcome instruments.

Methods

This is a multicenter retrospective observational study approved by our Institutional Review Board (HSD# STUDY00001714).

Study design and participants

A literature search was performed to identify institutions that had clinical outcome data for total shoulder arthroplasties that used one of two very similar designs of glenoid component: a DePuy Anchor Peg (DePuy, Warsaw, IN, USA) (Fig. 2) or a Wright Medical Perform Cortiloc (Wright Medical, Memphis, TN, USA) fluted central peg glenoid (Fig. 3). The corresponding authors were contacted and invited to participate by submitting de-identified data on each patient to this study.

Importantly, this investigation represented the variety of practice preferences of the participating surgeons using these glenoid components. There was no attempt to standardize patient evaluation and management, except for the design of glenoid component used. Each surgeon applied his own approach to preoperative radiographic evaluation (plain films, MRI or CT scan) and each applied his own indications and technique for total shoulder arthroplasty using this glenoid component design. Each participating surgeon completed a standardized data sheet including age at surgery, sex, year of surgery, diagnosis, preoperative glenoid type [32–34], glenoid retroversion, prior surgery, humeral component type, glenoid component, and humeral and glenoid component articular surface diameters of curvature. Each center used one or more of the following validated outcome scores to evaluate the clinical results of the arthroplasty: Simple Shoulder Test (SST), American Shoulder and Elbow Score (ASES), Constant Score (CS), or Penn Score.

Subjects were included in our analysis if they were between ages 18–99, had a shoulder arthroplasty procedure

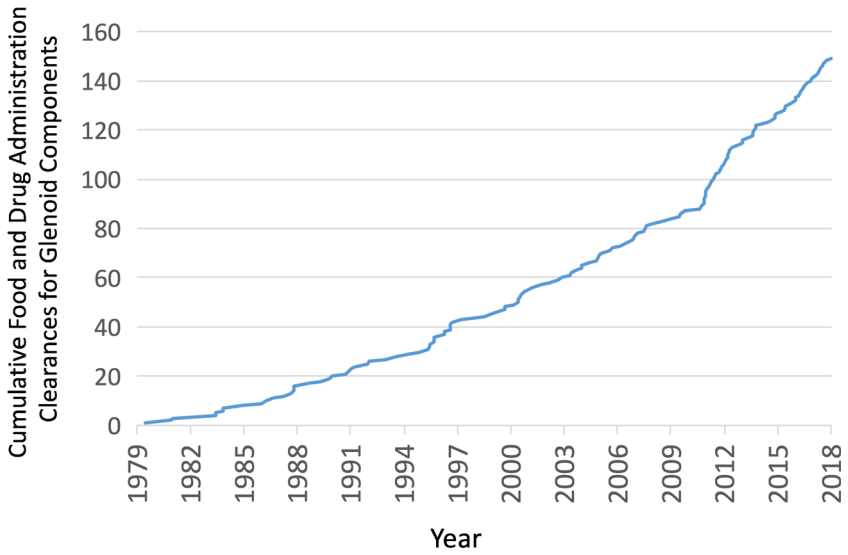

Fig. 1 Cumulative number by year of United States Food and Drug Administration 510(k) clearances for glenoid components or total shoulder arthroplasty systems including a glenoid component

performed for arthritis with an all-polyethylene fluted central peg glenoid component between 2000 and 2016, and had functional outcome scores preoperatively and at 1 or 2 years after surgery.

The clinical significance of the preoperative to postoperative improvement in each clinical score was assessed in two ways. First, the published value for the minimal clinically important difference (MCID) for each outcome scale was obtained from the literature: the Simple Shoulder Test (1.5), the American Shoulder Elbow Surgeons Score (13.6), the Constant Score (5.7), and the Penn Score (11.4) [35–37]. Each patient's scores were examined to determine if the improvement exceeded the MCID. Second, the maximal possible improvement for each patient was determined as the difference between the maximal possible value for the outcome scale and the patient's preoperative score. The amount of improvement achieved by each patient was then divided by the maximal possible improvement to obtain the percent of maximal possible improvement (%MPI)—clinically significant improvement has been defined as improvement of at least 30% of the maximal possible improvement [12, 27, 38–42].

One- and 2-year outcomes were characterized as the amount of improvement on each scale in comparison to the MCID and as the percentage of maximum possible improvement (%MPI). To enable comparison among the different scales, the 12-point Simple Shoulder Test was rescaled to a 0–100 scale [36]. Associations between risk factors and outcomes were estimated using multiple linear regression of the outcomes on each risk factor, adjusting for the practice site and the baseline value of the outcome score.

All calculations were carried out by an experienced statistician in R version 3.4.3 (Vienna, Austria) [42].

Results

In all, 1270 individual patients from 11 centers met the criteria for inclusion (Table 1). The typical patient had osteoarthritis, was 66 years of age at the time of surgery, and had surgery in 2011. The glenoid types reported by the surgeons were A1 (28.5%), A2 (29.2%), B1 (15.3%), and B2 (26.1%). Preoperative glenoid version averaged 12 ± 9°; 30% had retroversion greater than 15°. Seventy percent of the humeral components were standard stems, 18% short stems, and 12% stemless. The Anchor Peg glenoid was used in 65% and the Cortiloc glenoid in 35%. The average diameter of curvature of the humeral component was 49 ± 4 mm and that of the glenoid was 51 ± 6 mm. Preoperative and postoperative function was assessed by the Simple Shoulder Test in 654, the ASES score in 757, the Constant score in 446, and the PENN score in 16 (note that some patients were assessed by multiple scores).

Fig. 2 The Anchor Peg Glenoid Component, DePuy Synthes, 325 Paramount Dr., Raynham, MA 02767

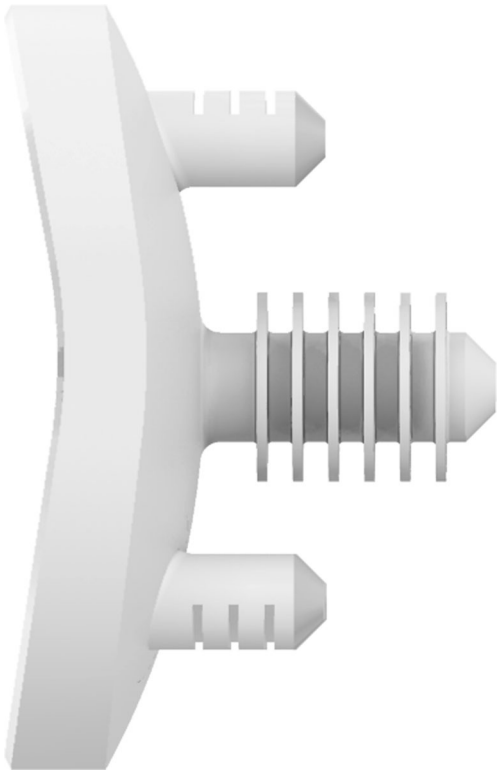

Fig. 3 Wright Medical Perform Cortiloc fluted central peg glenoid, Wright Medical, 1023 Cherry Road, Memphis, TN 38117

Twenty-five shoulders (2%) were reported to have had a second surgical procedure following their initial total shoulder arthroplasty. The types of second surgery were not further detailed in this study of clinical outcomes. With the exception of patient age, no preoperative patient or shoulder characteristics were significantly associated with the need for a second surgery. The odds ratio for revision by age at surgery (per 10 years) was 0.62 (95% CI 0.44–0.90, $p = 0.014$).

The great majority of these patients improved by more than the minimal clinically important difference and improved by more than 30% of the maximal possible improvement (MPI) (Table 2). The mean ± SD preoperative scores improved from SST 3 ± 2, ASES 37 ± 15, Constant score 36 ± 16, and Penn score 30 ± 19 to SST 10 ± 2, ASES 90 ± 12, Constant 76 ± 13, and Penn 80 ± 24 ($p < 0.001$ for each). For patients assessed with the SST, over 90% exceeded the MCID of 1.5 and improved by 30% of the MPI. For patients assessed with the ASES score, over 95% exceeded the MCID of 13.6 and improved by over 30% of the MPI. For patients assessed with the Constant score, over 90% exceeded the MCID of 5.7 and improved by over 30% of the MPI. Finally, for patients assessed with the Penn score, over 85% exceeded the MCID of 11.4 and improved by over 30% of the MPI.

For patients with data at both 1 and 2 years after surgery, there was little clinical improvement in outcome scores between year 1 and 2, even though some of the differences were statistically significant (Fig. 4).

These outcomes for the standard, non-augmented glenoid component were realized in cases with a range of patient and shoulder characteristics (Table 1), including the 41% of cases that had type B glenoids and the 30% of cases that had more than 15° of glenoid retroversion. The outcomes for shoulders with retroverted or type B glenoids were not inferior to those with neutral version or type A glenoids, respectively (Appendix Tables 4 and 5). The clinical outcomes were not consistently associated with the degree of mismatch between the humeral and glenoid diameters of curvature [43, 44].

Table 1 Descriptive statistics for preoperative characteristics

	N	*N* (%) or mean ± SD (range)
Male	1270	676 (53.2%)
Diagnosis		
Osteoarthritis	1270	1165 (91.7%)
Rheumatoid arthritis	1270	17 (1.3%)
Capsulorrhaphy arthropathy	1270	26 (2.0%)
Post traumatic arthritis	1270	37 (2.9%)
Avascular necrosis	1270	29 (2.3%)
Other	1270	220 (17.3%)
Age at surgery	1270	66.3 ± 9.5 (24, 93)
Year of surgery	1181	2011 ± 3 (2000, 2016)
Preoperative glenoid type	950	
A1		271 (28.5%)
A2		277 (29.2%)
B1		145 (15.3%)
B2		248 (26.1%)
C		8 (0.8%)
C1		1 (0.1%)
Preoperative glenoid retroversion (degrees)	649	12.2 ± 8.7 (− 8.4, 46.0)
Anteversion (less than zero degrees of retroversion)		20 (3.1%)
Neutral version (zero to 15°)		433 (66.7%)
More than 15° of retroversion		196 (30.2%)
Surgery on shoulder prior to arthroplasty	1228	177 (14.4%)
Humeral component stem	1265	
Standard		887 (70.1%)
Short		221 (17.5%)
Stemless		157 (12.4%)
Glenoid component	1269	
Anchor Peg		820 (64.6%)
Cortiloc		449 (35.4%)
Humeral component articular surface diameter of curvature (mm)	1177	49.1 ± 4.3 (38.0, 56.0)
Glenoid component articular surface diameter of curvature (mm)	1266	51.4 ± 6.0 (40.0, 67.8)

Table 2 Descriptive statistics: preoperative, 1-year postoperative, and 2-year postoperative for four different outcome scales

	American Shoulder and Elbow Surgeons Score	Simple Shoulder Test Score	Constant Score	Penn Score
Preoperative				
N	757	654	446	16
Mean ± SD	36.9 ± 14.7	3.3 ± 2.3	36.2 ± 15.9	29.7 ± 19.2
Range	2 to 85	0 to 11	2 to 83	6.9 to 78.3
Year 1 score				
N	691	588	378	1
Mean ± SD	89.0 ± 11.4*	9.9 ± 2.2*	75.2 ± 11.6*	97.2 ± NA
Range	10 to 100	1 to 12	23 to 97	97.2 to 97.2
N (%) improved by MCID	681 (98.6%)	564 (95.9%)	359 (96.0%)	1 (100.0%)
Year 2 score				
N	400	574	387	15
Mean ± SD	89.5 ± 12.1*	10.1 ± 2.3*	75.5 ± 12.9*	79.5 ± 24.0*
Range	17 to 100	0 to 12	9 to 98	6.0 to 100.0
N (%) improved by MCID	392 (98.0%)	551 (96.0%)	361 (94.3%)	14 (93.3%)
Year 1 %MPI				
N	691	588	374	1
Mean ± SD	82.6 ± 18.0	75.0 ± 28.8	58.8 ± 22.2	86.9 ± NA
Range	− 35.0 to 100.0	− 300.0 to 100.0	− 51.6 to 96.1	86.9 to 86.9
N (%) improved by 30%	682 (98.7%)	549 (93.4%)	342 (91.4%)	1 (100.0%)
Year 2 %MPI				
N	400	574	383	15
Mean ± SD	81.8 ± 28.4	77.6 ± 26.0	60.1 ± 23.2	73.0 ± 28.5
Range	− 315.0 to 100.0	− 100.0 to 100.0	− 66.7 to 97.4	− 6.4 to 100.0
N (%) improved by 30%	391 (97.8%)	544 (94.8%)	347 (90.6%)	13 (86.7%)

*p value for improvement over preoperative score < 0.0001

A comparison of the percent of maximal possible improvement for the SST, ASES, and Constant scores for ten different sites is shown in Table 3. Each scale at each site showed values for the average percent of maximal possible improvement that easily exceeded the threshold of 30%.

Discussion

This study design is unique in that it analyzes the early total shoulder clinical outcomes at the discrete time points of 1 and 2 years for 1270 individual patients from 11 independent international centers using a standard design all-polyethylene glenoid component with a fluted central peg and three cemented peripheral pegs.

As assessed by generally accepted outcome instruments, the average improvement in comfort and function achieved by these individual patients easily exceeded the published values for the minimal clinically important difference and provided well over 30% of the maximum possible improvement.

For patients having results at both the year 1 and year 2 time points, the improvement after the first year was small: 0.2 ± 1.5 for the SST, 0.8 ± 8.9 for the ASES score, and 0.5 ± 8.0 for the Constant score. This observation suggests that most of the clinical improvement after a total shoulder arthroplasty

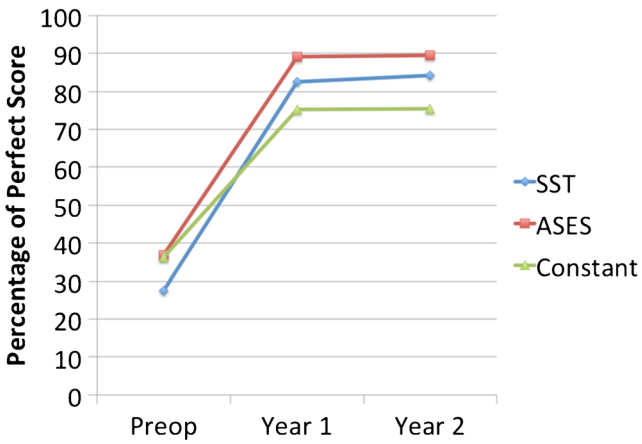

Fig. 4 Average SST, ASES, and Constant scores before and at 1 and 2 years after surgery for patients receiving a standard all-polyethylene glenoid component with a fluted central peg. Vertical axis indicates the percentage of a perfect score. Data for the Penn Score are not shown because of the small number of patients assessed with this score

Table 3 % MPI (mean ± SD) by outcome scale for the 10 sites using ASES, Constant, and SST scales

	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Site H	Site I	Site J
ASES										
Year 1	63 ± 10	84 ± 22		83 ± 22			87 ± 13		51 ± 6	
Year 2	68 ± 9	81 ± 43		86 ± 21			86 ± 14	79 ± 32	63 ± NA	
Constant										
Year 1	61 ± 10	67 ± 22		62 ± 16					49 ± 8	40 ± 31
Year 2	65 ± 8	64 ± 25		63 ± 21				50 ± 16	63 ± NA	45 ± 29
SST[a]										
Year 1	78 ± 12		75 ± 28	78 ± 39	82 ± 15	68 ± 28			56 ± 10	
Year 2	84 ± 9		72 ± 27	81 ± 30	82 ± 16	74 ± 28			75 ± NA	

[a] For comparison with the other scores, the usual 0 to 12 point SST score was rescaled as 0 to 100

occurs within the first year; therefore, year 1 data may be sufficient for characterizing the early outcomes for total shoulder arthroplasty with different glenoid component designs [36].

An interesting finding in this analysis was that with this basic glenoid component design, type B glenoids and glenoids with more than 15° of retroversion did not have outcomes that were inferior to those with less severe glenoid pathoanatomy. While special glenoid components have been designed for the type B retroverted glenoid [26, 45, 46], our study and other recent publications [27, 39, 47, 48] point out that the role for these special components has yet to be clarified.

The clinical outcomes reported were qualitatively similar among the different scoring systems used by the different centers. The application of published values for the MCID and the use of the percent of maximal possible improvement offer the possibility of comparing outcomes obtained with different outcome instruments.

The results of this study should be considered in light of certain limitations. First, this study focused only on the improvement in standard, validated, widely used, and universally available clinical outcome scales—Simple Shoulder Test, American Shoulder and Elbow score, Constant Score, and Penn Score—each of which has a defined MCID. Range of motion estimates and radiographic interpretations by the surgeons were not included in this analysis. Second, this study focused on the clinical improvement at discrete time points: 1 and 2 years after surgery, rather than mixing outcomes recorded over a range of years. While both 1 and 2-year follow-up data were not available for all patients, the results available at both of the two time points were quite similar [36]. Third, while most of the variables we assessed did not have a consistent, statistically significant effect on the outcome, some of these effects may have become significant if the number of patients was larger. Fourth, there was no attempt on our part to standardize the indications for surgery, the preoperative clinical or radiographic evaluation, the choice of humeral component, the surgical technique, or the postoperative rehabilitation program; instead, the surgeons treated each of their patients according to their personal practice guidelines. The consistency of the outcomes among these varied practices indicates the general utility of this design of glenoid component. Fifth, this study did not investigate component revision and survivorship, which require follow-up of 5 years or longer to obtain meaningful data [9, 22, 49, 50]. Finally, the surgeons whose patients were included in this analysis each had substantial experience in shoulder arthroplasty; the outcomes reported here might not be generalizable to the practices of surgeons with less experience [47, 51–56].

This report provides a broad-based and well-characterized data set against which the 1- and 2-year clinical outcomes for different glenoid components can be compared using universally available assessment scales (SST, ASES, Constant, Penn). Such comparisons are becoming increasing necessary and timely: new shoulder arthroplasty systems are being introduced annually without evidence that their clinical outcomes are superior to or even equal to those in current use [12]. Thus, a strong case exists for establishing a reference of 1- and 2-year clinical outcomes for standard glenoid components—such as that presented in this report—against which the early performance of new components can be compared. The results of this study suggest a possible benchmark for shoulders having pre and postoperative SST, ASES, Constant, or Penn scores: at 1 and 2 years after total shoulder arthroplasty, 90% of the shoulders are improved by the minimal clinically important difference and are improved by 30% of the maximal possible improvement.

Conclusion

The strength of this study lies in its demonstration that surgeons in 11 independent practices using their individual

approaches to patient selection, preoperative evaluation, surgical technique, and outcome evaluation were able to obtain robust early clinical outcomes in an international group of over 1200 individual patients using a basic all-polyethylene glenoid component. These data provide a basis for comparison with newer designs to determine whether these new designs lead to better early clinical outcomes.

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Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This was a retrospective cohort study approved by our Institutional Review Board (HSD# STUDY00001714). For this type of study, formal consent is not required.

Informed consent N/A.

Conflict of interest Financial remuneration the authors, or any member of their family, may have received directly related to the subject of the article: none.

The following is blinded for review purposes:

Dr. Matsen (first and corresponding author), Dr. De Wilde, Dr. Groh, Dr. Kilian, Dr. Merolla, Mr. Neradilek, Dr. Porcellini, Ms. Russ, Dr. Somerson, and Dr. Vidil have no conflict of interests to report.

The following doctors have conflict of interests outside of the submitted work as noted:

Dr. Iannotti reports personal fees from DePuy Synthes, personal fees from DJO Surgical, personal fees from Wright Tornier, from null, outside the submitted work.

Dr. Churchill reports personal fees from Wright Medical Tornier, Inc., during the conduct of the study; personal fees from Wright Medical Tornier, Inc., outside the submitted work. In addition, Dr. Churchill has a patent Glenoid Anchor Post licensed to Tornier Inc.

Dr. Edwards reports personal fees and non-financial support from Wright Medical Inc., during the conduct of the study; personal fees and non-financial support from Wright Medical Inc., outside the submitted work; and royalties and consulting fees from Wright Medical Inc. & DJO.

Dr. Evans reports other from DePuy-Johnson and Johnson, outside the submitted work.

Dr. Fehringer reports grants from University of Nebraska Medical Center, other from Wright Medical, during the conduct of the study.

Dr. Kelly reports other from Wright Medical, during the conduct of the study; personal fees and other from Wright Medical, outside the submitted work.

Dr. Norris reports personal fees and other from Wright Medical, during the conduct of the study.

Dr. Spencer reports personal fees from Tornier/Wright, outside the submitted work.

Dr. Wirth reports other from DePuy-Johnson and Johnson, other from Wright Medical, other from Elsevier, grants from Arthrex, outside the submitted work. In addition, Dr. Wirth has a patent with royalties paid.

Appendix

Table 4 Association of risk factors with % MPI by outcome scale and follow-up year

Risk factor	ASES		Constant Score		SST100	
	Year 1 (N = 690–691[1]) Coef (95% CI)	Year 2 (N = 400[2]) Coef (95% CI)	Year 1 (N = 370–374[3]) Coef (95% CI)	Year 2 (N = 380–383[4]) Coef (95% CI)	Year 1 (N = 551–588[5]) Coef (95% CI)	Year 2 (N = 532–574[6]) Coef (95% CI)
Male	0.9 (− 1.6, 3.4)	*6.3 (0.7, 12.0)*	*5.8 (1.6, 10.0)*	*9.0 (4.5, 13.6)*	*5.0 (0.2, 9.9)*	*6.8 (2.4, 11.3)*
Diagnosis						
Osteoarthritis	1.4 (− 6.8, 9.6)	8.7 (− 4.0, 21.3)	6.9 (− 0.1, 13.8)	*15.1 (7.4, 22.7)*	13.2 (5.2, 21.2)[a]	10.6 (3.2, 18.1)[b]
Rheumatoid arthritis	− 6.3 (− 16.9, 4.2)	*	− 17.6 (− 31.4, − 3.8)[c]	*− 25.2 (− 40.2, − 10.2)*	*	*
Capsulorrhaphy arthropathy	4.7 (− 4.3, 13.8)	8.1 (− 11.7, 28.0)	4.0 (− 9.7, 17.6)	2.5 (− 13.6, 18.6)	8.9 (− 6.7, 24.5)	4.9 (− 11.3, 21.1)
Post-traumatic arthritis	*− 16.0 (− 25.3, − 6.7)*	*	− 21.0 (− 32.9, − 9.1)[d]	− 18.0 (− 32.0, − 3.9)[e]	*− 28.8 (− 41.6, − 16.1)*	*− 26.9 (− 38.5, − 15.2)*
Avascular necrosis	− 2.3 (− 12.6, 8.0)	*	− 1.6 (− 16.6, 13.4)	*− 20.0 (− 34.6, − 5.4)*	− 16.2 (− 34.9, 2.5)	− 7.0 (− 25.1, 11.2)
Other	− 3.5 (− 8.6, 1.6)	− 1.0 (− 26.1, 24.1)[f]	3.5 (− 12.6, 19.5)[g]	− 4.7 (− 24.0, 14.6)	− 12.8 (− 29.3, 3.6)	− 9.3 (− 23.8, 5.2)
Age at surgery, per 10 years	*1.6 (0.2, 2.9)*	1.1 (− 2.2, 4.4)	*3.2 (1.0, 5.4)*	2.2 (− 0.2, 4.7)	0.7 (− 1.7, 3.2)	2.0 (− 0.2, 4.3)

Table 4 (continued)

Risk factor	ASES		Constant Score		SST100	
	Year 1 (N = 690–691[1]) Coef (95% CI)	Year 2 (N = 400[2]) Coef (95% CI)	Year 1 (N = 370–374[3]) Coef (95% CI)	Year 2 (N = 380–383[4]) Coef (95% CI)	Year 1 (N = 551–588[5]) Coef (95% CI)	Year 2 (N = 532–574[6]) Coef (95% CI)
Year of surgery, per 5 years	*− 3.6 (− 6.4, − 0.7)*	8.0 (− 5.9, 21.9)	*− 15.0 (− 22.0, − 8.1)*	*− 11.7 (− 20.4, − 2.9)*	− 2.7 (− 10.3, 4.9)	− 1.7 (− 8.6, 5.2)
Preoperative glenoid type						
A1	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)
A2	− 0.9 (− 6.4, 4.6)	− 0.7 (− 9.6, 8.2)	− 1.6 (− 7.1, 3.9)	0.7 (− 5.5, 6.9)	1.3 (− 5.6, 8.1)	1.7 (− 4.9, 8.3)
B1	4.0 (− 1.5, 9.5)	1.4 (− 7.3, 10.1)	1.9 (− 3.6, 7.3)	1.2 (− 4.9, 7.2)	5.3 (− 2.4, 13.0)	5.2 (− 2.2, 12.5)
B2	− 2.7 (− 8.0, 2.6)	− 0.5 (− 9.0, 8.0)	3.8 (− 1.8, 9.4)	2.9 (− 3.1, 8.9)	5.0 (−2.7, 12.6)	3.5 (− 3.8, 10.9)
C	2.6 (− 10.8, 15.9)	4.3 (− 19.7, 28.2)	− 6.9 (− 22.8, 8.9)	− 1.1 (− 18.8, 16.5)	10.9 (− 17.5, 39.3)	11.7 (− 14.3, 37.8)
Preoperative glenoid retroversion, per 10°	1.5 (− 12.3, 15.2)	14.0 (− 9.1, 37.1)	*23.0 (10.0, 35.9)*	*19.9 (8.1, 31.8)*	5.4 (− 3.6, 14.4)	8.3 (−0.6, 17.3)
Preoperative glenoid retroversion	0.5 (− 4.1, 5.1)	4.7 (− 3.0, 12.4)	*7.7 (3.3, 12.0)*	*6.6 (2.7, 10.6)*	1.8 (− 1.2, 4.8)	2.8 (− 0.2, 5.8)
Neutral version (zero to 15°)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)
Anteversion (less than zero degrees of retroversion)	6.9 (− 30.4, 44.1)[h]	3.4 (− 95.4, 102.3)	3.9 (− 36.8, 44.7)	–	4.1 (− 9.9, 18.2)	− 0.2 (− 13.9, 13.4)
More than 15° of retroversion	2.4 (− 3.6, 8.4)	6.7 (− 5.3, 18.8)	5.8 (− 0.8, 12.5)[i]	*7.4 (0.7, 14.0)*	4.6 (− 1.2, 10.5)	6.0 (− 0.2, 12.1)
Surgery on shoulder prior to arthroplasty	*− 8.5 (− 12.2, − 4.8)*	− 11.9 (− 19.6, − 4.3)[j]	− 6.3 (− 12.0, − 0.5)[k]	− 8.3 (− 14.3, − 2.4)[l]	− 4.3 (− 11.3, 2.7)	− 5.6 (− 12.0, 0.8)
Humeral component stem						
Standard	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)
Short	12.0 (− 4.5, 28.6)	7.4 (− 47.8, 62.5)	25.7 (− 12.3, 63.6)	21.6 (− 20.6, 63.8)	20.0 (− 8.4, 48.5)	9.1 (− 42.0, 60.3)
Stemless	− 2.0 (− 15.2, 11.3)	11.1 (− 21.1, 43.4)	34.8 (− 3.3, 73.0)	26.7 (− 16.0, 69.4)	22.3 (− 5.8, 50.3)	6.5 (− 44.3, 57.3)
Glenoid component, Cortiloc (vs. Anchor Peg)	*− 3.8 (− 7.2, − 0.4)*	*− 13.6 (− 26.9, − 0.3)*	*13.6 (7.1, 20.2)*	*15.5 (6.9, 24.0)*	20.0 (− 8.4, 48.5)	9.1 (− 42.0, 60.3)
Humeral component articular surface diameter of curvature, per 5 mm	1.4 (− 0.0, 2.9)	*5.8 (2.3, 9.3)*	*6.0 (3.3, 8.6)*	*6.9 (4.0, 9.8)*	*6.7 (3.1, 10.2)*	*6.1 (2.9, 9.3)*
Glenoid component articular surface diameter of curvature, per 5 mm	*2.4 (0.9, 3.8)*	*5.0 (1.5, 8.4)*	*5.7 (3.1, 8.4)*	*8.1 (5.4, 10.9)*	*6.6 (3.4, 9.8)*	*6.5 (3.6, 9.3)*

Linear regression adjusted for baseline score and site. Effects with $p < 0.05$ (and with both statistical significance and direction unaffected by influential observations) are in italics

SST100 SST rescaled to the 0–100 range

*Effect not shown as it is not estimable when a small number of influential observations is excluded

[1] Except N = 380 for glenoid type and N = 168 retroversion degrees, [2] except N = 352 for glenoid type and N = 187 retroversion degrees, [3] except N = 233 retroversion degrees, [4] except N = 237 retroversion degrees, [5] except N = 499 for year, N = 347 for retroversion degrees and N = 497 for humeral component curvature, [6] except N = 485 for year, N = 334 for retroversion degrees and N = 483 for humeral component curvature

Results without influential observation(s) (presented only when the statistical significance changes or the statistical significance remains but the sign changes): [a] Coef (95% CI) = 1.8 (− 5.1, 8.6) (4 observations excluded), [b] Coef (95% CI) = 2.7 (− 4.5, 10.0) (4 observations excluded), [c] Coef (95% CI) = − 13.9 (− 50.0, 22.1) (8 observations excluded), [d] Coef (95% CI) = − 12.2 (− 48.6, 24.2) (9 observations excluded), [e] Coef (95% CI) = − 10.1 (− 51.2, 31.0) (8 observations excluded), [f] Coef (95% CI) = 18.6 (9.3, 27.9) (5 observations excluded), [g] Coef (95% CI) = 8.5 (3.2, 13.8) (9 observations excluded), [h] Coef (95% CI) = 39.4 (10.5, 68.2) (5 observations excluded), [i] Coef (95% CI) = 4.9 (0.1, 9.7) (13 observations excluded), [j] Coef (95% CI) = − 4.2 (− 9.6, 1.3) (2 observations excluded), [k] Coef (95% CI) = − 4.3 (− 10.0, 1.3) (1 observation excluded), [l] Coef (95% CI) = − 4.1 (− 9.8, 1.7) (3 observations excluded)

Table 5 Association of risk factors with post-op score by scale and year

Risk factor	ASES		Constant Score		SST100	
	Year 1 (N = 690–691[1]) Coef (95% CI)	Year 2 (N = 400[2]) Coef (95% CI)	Year 1 (N = 370–374[3]) Coef (95% CI)	Year 2 (N = 380–383[4]) Coef (95% CI)	Year 1 (N = 551–588[5]) Coef (95% CI)	Year 2 (N = 532–574[6]) Coef (95% CI)
Male	0.9 (− 0.7, 2.4)	*3.9 (1.6, 6.2)*	*3.7 (1.4, 6.0)*	*5.6 (3.0, 8.2)*	*3.3 (0.4, 6.3)*	*4.3 (1.1, 7.4)*
Diagnosis						
Osteoarthritis	− 1.4 (− 6.3, 3.6)	4.6 (− 0.6, 9.9)	3.8 (− 0.0, 7.6)	*10.4 (6.0, 14.8)*	5.3 (0.4, 10.2)[a]	7.2 (1.9, 12.4)[b]
Rheumatoid arthritis	− 2.9 (− 9.3, 3.5)	*	− 10.6 (− 18.2, − 2.9)[c]	− 17.5 (− 26.1, − 8.9)[d]	− 14.0 (− 31.5, 3.6)	*
Capsulorrhaphy arthropathy	2.4 (− 3.1, 7.9)	3.0 (− 5.2, 11.2)	2.6 (− 4.9, 10.2)	1.3 (− 8.0, 10.6)	5.6 (− 3.9, 15.2)	1.1 (− 10.4, 12.6)
Post-traumatic arthritis	*− 8.6 (− 14.2, − 2.9)*	*− 12.9 (− 22.1, − 3.6)*	− 11.2 (− 17.7, − 4.6)[e]	− 9.6 (− 17.7, − 1.5)[f]	*− 9.7 (− 17.6, − 1.8)*	*− 14.7 (− 23.0, − 6.4)*
Avascular necrosis	− 0.7 (− 6.9, 5.6)	*	− 3.4 (− 11.7, 4.9)	*− 17.1 (− 25.5, − 8.8)*	− 10.8 (− 22.3, 0.6)	− 5.7 (− 18.5, 7.1)
Other	− 1.7 (− 4.8, 1.4)	− 0.0 (− 10.4, 10.4)	2.9 (− 6.0, 11.7)	0.4 (− 10.8, 11.5)	− 8.2 (− 18.2, 1.9)	− 7.4 (− 17.6, 2.8)
Age at surgery, per 10 years	*1.2 (0.4, 2.0)*	0.9 (− 0.5, 2.3)	*1.9 (0.7, 3.1)*	1.3 (− 0.1, 2.7)	0.7 (− 0.8, 2.3)	*1.8 (0.3, 3.4)*
Year of surgery, per 5 years	*− 2.8 (− 4.5, − 1.1)*	5.8 (0.1, 11.5)[g]	*− 9.8 (− 13.6, − 6.0)*	*− 8.3 (− 13.3, − 3.3)*	− 1.8 (− 6.3, 2.8)	− 0.6 (− 5.4, 4.3)
Preoperative glenoid type						
A1	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)
A2	0.0 (− 3.2, 3.3)	− 0.8 (− 4.4, 2.7)	− 0.4 (− 3.5, 2.6)	0.7 (− 2.9, 4.3)	− 0.8 (− 5.0, 3.4)	0.4 (− 4.3, 5.0)
B1	1.9 (− 1.4, 5.1)	0.1 (− 3.3, 3.6)	1.5 (− 1.5, 4.6)	0.9 (− 2.6, 4.4)	1.2 (− 3.5, 5.9)	2.5 (− 2.7, 7.7)
B2	− 1.2 (− 4.3, 1.9)	0.5 (− 2.9, 3.9)	2.8 (− 0.2, 5.9)	2.1 (− 1.4, 5.5)	1.5 (− 3.2, 6.2)	1.1 (− 4.0, 6.3)
C	2.4 (− 5.5, 10.2)	2.8 (− 6.7, 12.4)	− 2.6 (− 11.3, 6.2)	0.9 (− 9.3, 11.1)	5.1 (− 12.3, 22.5)	7.2 (− 11.2, 25.5)
Preoperative glenoid retroversion, per 10°	0.5 (− 2.0, 2.9)	*2.8 (0.1, 5.5)*	*4.8 (2.3, 7.2)*	*4.5 (2.2, 6.9)*	1.5 (− 0.8, 3.7)	1.8 (− 0.5, 4.2)
Preoperative glenoid retroversion						
Neutral version (0° to 15°)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)
Anteversion (less than 0° of retroversion)	2.1 (− 17.8, 21.9)	− 0.4 (− 34.6, 33.9)	9.4 (− 13.7, 32.4)		3.9 (− 6.7, 14.5)	1.1 (− 9.5, 11.6)
More than 15° of retroversion	1.0 (− 2.2, 4.1)	3.4 (− 0.8, 7.5)	3.7 (− 0.1, 7.4)	*4.8 (0.8, 8.8)*	3.8 (− 0.6, 8.2)	4.3 (− 0.4, 9.1)
Surgery on shoulder prior to arthroplasty	*− 4.6 (− 6.9, − 2.4)*	*− 4.7 (− 7.8, − 1.5)*	− 2.4 (− 5.6, 0.8)	− 3.4 (− 6.8, 0.0)	− 2.9 (− 7.1, 1.3)	*− 4.9 (− 9.4, − 0.3)*
Humeral component stem						
Standard	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)	0.0 (ref.)
Short	9.8 (− 0.2, 19.8)	5.5 (− 17.3, 28.2)	17.5 (− 3.5, 38.4)	15.6 (− 8.8, 39.9)	13.4 (− 4.0, 30.8)	6.9 (− 29.1, 43.0)
Stemless	− 1.8 (− 9.8, 6.3)	7.4 (− 5.9, 20.7)	*22.0 (0.9, 43.1)*	17.4 (− 7.2, 42.0)	15.4 (− 1.8, 32.6)	4.9 (− 30.9, 40.7)
Glenoid component, Cortiloc (vs. Anchor Peg)	*− 3.1 (− 5.1, − 1.0)*	*− 8.7 (− 14.2, − 3.3)*	*6.9 (3.3, 10.6)*	*9.1 (4.2, 14.0)*	13.4 (− 4.0, 30.8)	6.9 (− 29.1, 43.0)
Humeral component articular surface diameter of curvature, per 5 mm	0.7 (− 0.2, 1.6)	*2.5 (1.0, 3.9)*	*3.4 (1.9, 4.8)*	*3.8 (2.2, 5.5)*	*3.7 (1.6, 5.9)*	*3.6 (1.4, 5.8)*
Glenoid component articular surface diameter of curvature, per 5 mm	*1.4 (0.5, 2.2)*	*2.3 (0.8, 3.7)*	*3.5 (2.0, 4.9)*	*4.8 (3.2, 6.4)*	*4.0 (2.1, 6.0)*	*4.0 (1.9, 6.0)*

Linear regression adjusted for baseline score and site. Effects with $p < 0.05$ (and with both statistical significance and direction unaffected by influential observations) are in italics

SST100 SST rescaled to the 0–100 range

*Effect not shown as it is not estimable when a small number of influential observations is excluded

[1] Except N = 380 for glenoid type and N = 168 retroversion degrees, [2] except N = 352 for glenoid type and N = 187 retroversion degrees, [3] except N = 233 retroversion degrees, [4] except N = 237 retroversion degrees, [5] except N = 499 for year, N = 347 for retroversion degrees and N = 497 for humeral component curvature, [6] except N = 485 for year, N = 334 for retroversion degrees and N = 483 for humeral component curvature

Results without influential observation(s) (presented only when the statistical significance changes or the statistical significance remains but the sign changes): [a] Coef (95% CI) = 3.1 (− 1.8, 7.9) (2 observations excluded), [b] Coef (95% CI) = 4.5 (− 0.6, 9.7) (2 observations excluded), [c] Coef (95% CI) = − 11.3 (− 23.4, 0.9) (5 observations excluded), [d] Coef (95% CI) = − 14.7 (− 31.3, 1.8) (6 observations excluded), [e] Coef (95% CI) = − 10.2 (− 21.8, 1.4) (7 observations excluded), [f] Coef (95% CI) = − 6.1 (− 22.8, 10.7) (7 observations excluded), [g] Coef (95% CI) = 4.5 (− 1.3, 10.2) (1 observation excluded)

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